Research advance of biomass and carbon storage of poplar in China

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Abstract: This paper summarized the studies on biomass production, biomass growth models, biomass measurement, biomass and forest density, as well as carbon storage of poplars in China in recent 20 years. The existing problems on research of poplar biomass are discussed and some suggestions for enhancing biomass of poplars are put forward..

Keywords: Poplar, Biomass, Carbon Storage, Review

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Introduction

Global warming is becoming international environmental problem and has attracted much attention from many ecologists and environmentalists. Global warming is mainly resulted by CO_2 increase in atmosphere. Plants have an important role in immobilizing CO_2 and carbon storage in ecosystem. Therefore it is important to study the biomass and carbon storage of plants for decreasing greenhouse effect. Poplar is a fast-growing and high-yield species and has strong adaptive ability to ecological environment. Many researches on poplar biomass and carbon storage have been conducted in recent 20 years in China (Cao *et al*. 2002; Chen and Li 1984; Peng, *et al*. 2003; Shandong Provincial Academy of Forestry Science, 1990; Sun 1995; Sun *et al.* 1998; Wang 1999; Xu and Chen 1987; Xu and Zheng 1990; Yan and Li 1995; Zou *et al.* 1995; Xue and yang 2004; Li and Wang 1998).

There are over 100 species of poplar in the world and over 50 species in five groups across China (not including crossbreed and imported species). Poplar distributes widely in China due to its biological characters, covering Jilin and Inner Mongolia in the north, Xinjiang, Gansu in the west, Anhui, Zhejiang and Tibet in the south. The studies of poplar concerning biomass focused on biomass production, model of biomass growth, biomass measurement, and biomass and forest density.

This paper summarized the research advance on biomass and carbon storage of poplar in China and aimed to provide a reference for deeply studying the role of immobilizing CO_2 of poplar in ecosystem.

Biomass production

The locations and species concerning with poplar biomass study are shown in Table 1. Ecozone is from cold-warm zone, temperate zone, and sub-tropical to Qinghai-Tibet plateau. These studies began in the 1980s of 20th century and become more prevalent in recent years, involving 26 species and clones. The forest types are mainly timber plantations and protection plantations and stand age is from 1 to 33.

The biomass of the 9-year-old *Populus × euramericana* (Dode) Guinier, I-214, I-69/55, *Populus × canadaensis Moench. Cv., Populus canadaensis,* and I-72/58 were surveyed by Shandong Provincial Academy of Forestry Science (1990) in Changqing County, Shandong Province. The result shows that I-72/58 has the highest total biomass ($183.051×10^3$ kg·hm^{-2}), followed by *P. × euramericana (Dode) Guinier* ($158.104×10^3$kg·hm^{-2}) and *P. canadaensis* has the lowest total biomass ($74.237×10^3$ kg·hm^{-2}). It indicated that under the same site conditions, the difference in biomass of different species with same age is highly related to the biological characteristics of tree species. For example, the aboveground biomass ($122×10^3$ kg·hm^{-2}) of 6-year-old I-72 poplar in Yinan County of Shandong Province (Xu and Zheng 1990) is much high than the total biomass ($117× 10^3$ kg·hm^{-2}) of 12-year-old *P. tomentosa carr* in Guan County of Shandong Province (Xu and Chen 1987).

Since it is difficult to compare the biomass of different poplars species in different regions, we convert the biomass of poplars to the mean net production, and the order of net production for major poplar species is shown in Table 2.

Biomass production also varies with environments. Chen and Li (1984) studied the biomass and net production of *P. euphratica oliv* in Xinjiang Municipality. The results showed that the total biomass of *P. euphratica oliv* is $29.22×10^3$ kg·hm^{-2} and net production is $1.54×10^3$ kg·hm^{-2}·a^{-1} at age of 19. The net production of this species is much lower than that of other poplar species in other regions (Table 2). This is possibly due to that Xingjiang is a drought and less precipitation area.

Heilongjiang is a northern province in China, where the water and heat conditions for poplar growth is not as better as other provinces. However, *P. alba × P. bero linensis* displays excellent character in Heilongjiang (Yan and Li 1995). Its net production is only lower than that of I-72/58 and *P. × euramericana* (Dode) Guinier in Shandong, but higher than that of other poplar species in other provinces (Table 2). Thus *P. alba × P. bero linensis* is an excellent low-temperature-resistant and draught-resistant species in the North China. From Table 2, we also know that I72/58, *P. × euramericana (Dode) Guinier* and I-214 are good species to plant wildly in Shandong Province.

Compared to Chinese fir which is also a fast-growing and high-yielding species, the biomass of most poplars is higher than that of Chinese fir. Pan *et al*. (1978) estimated the biomass of

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11-year-old Chinese fir plantation in Huitong County of Hunan Province. It was 106×10^3 kg·hm^{-2} on valley site and 70.7×10^3 kg·hm^{-2} on slope site. Furthermore, the biomass of 23-year-old *Pinus sylvestris* var. *sylvestriformis* plantation, another fast-growing and high-yielding species in Changbai mountain in northeast China, is only 111.982×10^3 kg·hm^{-2} (Zou *et al.* 1995), which is lower than that of poplars.

Table 1. Study survey of poplar biomass

Location	Coordinate	Species	Forest type	Age	Ecozone	Reference
Luntai (Xinjiang)	E84°15′ N41°31′	*P. euphratica oliv.*	Forest for bank protection	6–33	warm temperate zone and desert region	Chen,1984
Guan (Shandong)	E115°27′ N36°30′	*P. tomentosa carr*	Forest network	12	warm temperate deciduous, broad leaved forest region	Xu, 1987
Changqing (Shandong)	E115°45′ N36°37′	*P. × euramericana (Dode) Guinier* *P. × Canadensis Moench.cv.* *P. Canadensis* I–214, I–69/55, I–72/58	Forest for high yield	9–14	warm temperate deciduous, broad leaved forest region	Shandong Provincial Academy of Forestry Science, 1990
Yinan (Shandong)	E115°45′ N36°37′	I–72	Forest for high yield	6	warm temperate deciduous, broad leaved forest region	Xu, 1990
Anqing Anhui	E115°46′ N36°36′	I–72,I–69	Forest for bank protection	9	sub-tropical seasonal wind region	Xing, 1991
Jianping (Liaoning)	E119°25′	P34, P06, P47, P48, P64, P51	seedling	1	cold temperate zone coniferous and broad leaved forest	Zhu, 1995
Tibet	E90°00′ N29°30′	*P. Szechuanica* var. *tibetica* Schneid, *P. beijingensis W. H. Hsu,* *P. nigra* var. *thevestina,* *P. alba L.*	Forest for field protection	10–19	Temperate zone monsoon semi-draught plateau	Guan, 1993
Qiqihar (Heilongjian)	E123°51′ N47°23′	*P. alba × P. bero linensis*	Forest for timber	15	cold temperate zone coniferous and broad leaved forest	Yan, 1995
Xinyi (Jiangsu)	N34°05′ E118°00′	W–46, I–69, NL–80105, NL–80205	Forest for field protection	4	seasonal wind semi-–humid region	Sun, 1995
Huaining (Anhui)	E115°45′ N36°37′	I–72, I–72/58, I–69, I–69/55	Forest for bank protection	6–7	sub-tropical seasonal wind region	Sun, 1998
Daocheng (Sichuan)	E100°11′ N29°03′,	*P. schneideri* var. *tibetica*	Forest for timber	9	Qinghai–tibet plateau	Peng, 2003
Linhe (Inner mogolia)	E106°25 N40°05′	*P. populars's*	Forest for field protection	13–14	temperate zone continental seasonal wind climate region	Sun, 2004
Gaoyou (Jiangsu)	E119°40′ N32°20′	I–69 (*P. deltoids barter.cv.'lux"ex*)	Forest for high yield	10	seasonal wind semi–humidity	Tang, 2004

Table 2. The biomass and productivity of some poplar species

Species	Location	Age	Biomass (10^3Kg·hm^{-2})	Net production (10^3Kg·hm^{-2}·a^{-1})	Order
I–72/58	Shandong	9	183.051	20.339	1
P. × euramericana (Dode) Guinier	Shandong	9	158.104	17.567	2
P. alba × P. bero linensis	Heilongjian	15	188.71	16.765	3
I–214	Shandong	9	149.441	16.605	4
I–69/55	Shandong	9	138.798	15.421	5
P. canadaensis Moench. *Cv.*	Shandong	9	134.208	14.912	6
P. tomentosa carr	Shandong	2-12	0.44-117.24	9.77	7
P. schneideri var. *tibetica*	Sichuan	9	58.391	9.342	8
P. canadaensis	Shandong	9	74.237	8.249	9
P. beijingensis W. H. Hsu	Tibet	11	61.259	5.569	10
P. nigra var. *thevestina*	Tibet	14	54.362	3.883	11
P. szechuanica var. *tibetica* Schneid	Tibet	14	35.784	2.556	12
P. alba L.	Tibet	13	29.926	2.302	13
P. euphratica oliv	Xinjiang	19	29.22	1.54	14

Model of biomass growth

Biomass growth is highly relative to tree diameter and height. A series of biomass models have been established to estimate the biomass of different poplar species (Table 3). The commonly used models for estimating biomass of poplars are: $W = A (D^2H)^B$ (Shandong Provincial Academy of Forestry Science 1990; Sun *et al*. 1998, Peng *et al*. 2003), $\mathrm{Log}W = \log A + B\log D^2H$ (Chen and Li 1984, Xu and Chen 1987), $W = A + B\ H^C\ D^D$ (Xu and Zheng 1990). The first model is mostly used by researcher. Peng (2003)

studied the biomass and production of *P. schneideri* var. *tibetica* He regarded the tree diameter and tree height (D^2H) as independent variable and the biomass of each organ of tree as dependent variable. Then he evaluated the adaptability of 4 regress models, $Y = a + BX$, $Y = aX^b$, $Y = ae^{bX}$, $Y = a + bn^X$, and selected $Y = aX^b$ as the optimal model for estimating biomass of poplars.

Table 3. The regression models established for estimating biomass of poplars

Species (location)	Regression models	H extent	D extent	W extent	Reference
P. euphratica oliv (Xinjiang)	$LogW_s=\log 0.0382+0.8837\log D^2H$	3.18-1254	3.5-33.5	0.76-89.61	Chen 1984
	$LogW_b=\log 0.1072+0.6350\log D^2H$	3.18-1254	3.5-33.5	1.25-225.61	
	$LogW_l=\log 0.0014+0.8134\log D^2H$	3.18-1254	3.5-33.5	0.04-9.33	
	$LogW_r=\log 0.1059+0.6185\log D^2H$	3.64-11.12	3.7-18.1	1.35-23.95	
	$LogW_{ul}=\log 0.1221+0.7813\log D^2H$	3.18-1254	3.5-33.5	1.95-324.3	
	$LogW_t=\log 0.5162+0.5985\log D^2H$	3.18-1254	3.5-33.5	6.21-80.29	
P. tomentosa carr (Shandong)	$LogW_s=-1.4614+0.9273\log D^2H$	7.4-18.3	9.3-20.0	12.13-114.51	Xu 1987
	$LogW_b=-2.1282+0.9767\log D^2H$			3.61-42.14	
	$LogW_l=-0.0525+0.7937\log D^2H$			2.20-11.30	
	$LogW_r=-1.7211+0.8566\log D^2H$			3.90-36.86	
	$LogW_t=-1.1142+0.8964\log D^2H$			21.84-187.7	
P. × Canadensis Moench. Cv. (Shandong)	$W_s=1.3715*10^{-2}(D^2H)^{1.00591}$	11-26	10-33		Xu 1987
	$W_b=2.2373*10^{-4}(D^2H)^{1.29693}$				
	$W_l=4.6208*10^{-3}(D^2H)^{0.80926}$				
	$W_r=9.8577*10^{-2}(D^2H)^{0.63615}$				
I-214 (Shandong)	$W_s=2.3549*10^{-3}(D^2H)^{1.18784}$	15-15	13-31		Xu 1987
	$W_b=8.6540*10^{-4}(D^2H)^{1.12873}$				
	$W_l=5.0719*10^{-2}(D^2H)^{0.53636}$				
	$W_r=2.5856*10^{-2}(D^2H)^{0.71964}$				
I-72 (Shandong)	$W_s=7.5361*10^{-3}(D^2H)^{1.06813}$	23-26	20-31		Xu 1987
	$W_b=8.5496*10^{-6}(D^2H)^{1.58946}$				
	$W_l=1.9300*10^{-4}(D^2H)^{1.09766}$				
	$W_r=1.3252*10^{-4}(D^2H)^{1.221.8}$				
I-69/55 (Shandong)	$W_s=3.0966*10^{-3}(D^2H)^{1.16194}$	25-27	20-30		Xu 1987
	$W_b=1.1870*10^{-4}(D^2H)^{1.32628}$				
	$W_l=4.2221*10^{-2}(D^2H)^{0.55252}$				
	$W_r=1.6789*10^{-3}(D^2H)^{1.02004}$				
I-72 (Shandong)	$W_s=0.04+7.3641\times10^{-11}H^{3.024}D^{3.3571}$				Xu 1990
	$W_b=0.0002+2.6982\times10^{-5}H^{-0.2513}D^{2.3169}$				
	$W_l=0.0047+3.511\times10^{-10}H^{1.1342}D^{4.2984}$				
	$W_r=0.003+6.3101\times10^{-8}H^{-2.3038}D^{0.7405}$				
Poplars on beach (Anhui)	$W_s=0.0319(D^2H)^{0.6992}$				Sun 1998
	$W_b=0.0669(D^2H)^{0.5188}$				
	$W_l=0.0114(D^2H)^{0.7036}$				
	$W_r=(0.0062(D^2H))^{0.9480}$				
	$W_t=0.1472(D^2H)^{0.7852}$				
P. schneideri var. *tibetica* (Sichuan)	$W_s=0.0527(D^2H)^{0.08023}$	3.9-9.5	2.3-16.2	0.486-25.936	Peng 2003
	$W_p=0.0069(D^2H)^{0.8449}$			0.052-4.084	
	$W_b=0.0377(D^2H)^{0.6679}$			0.329-7.50	
	$W_l=0.0089(D^2H)^{0.7269}$			0.097-3.07	
	$W_r=0.0445(D^2H)^{0.7596}$			0.392-16.181	
	$W_t=0.1535(D^2H)^{0.7601}$			0.356-56.771	
W-46 *etc.* (Jiangsu)	$LogW_s=1.0659\log D^2H-2.1305$				Sun 1995
	$LogW_b=0.9911\log D^2H-1.3791$				
	$LogW_l=0.4489\log D^2H-1.1455$				
	$LogW_r=0.7061\log D^2H-1.2588$				

Biomass measurement of different organs of tree

Different species have different proportions of biomass for each organ of tree. The Table 4 shows that the biomass percentage of different organs of nine poplar species. Among the nine species listed in Table 4, the percentage of stem biomass of I-72/58 poplar is greatest (64.06%), so this species can be selected as a high yield species. The biomass percentages of stems of *P. alba* × *P. bero linensis* (Heilongjiang) and *P. schneideri* var. *tibetica* (Sichuan) are lower (about 53%) than other species, but their root biomass percentages are relative high compared with other species. As a result, these two species are fitting to construct ecological and economic protective forest. The biomass of *P. tomentosa carr* was measured in every age class (Xu 1987). Result shows that the biomass percentage of stem and branch of this species increased with age, especially in the first 10 years after planting, while the biomass percentage of leaf and root decreased with age increasing. Similar results were obtained for *P.* × *Canadensis* Moench. *Cv.* by Shandong Provincial Academy of Forestry Science 1990).

Table 4. The percentage of biomass of different organs of poplars

Species	Biomass percentage of different organs (%)					
	Age	Stem	Branch	Leaf	Root	Bark
P. tomentosa carr	2-12	41.9-61.53	0-18.02	32.38-3.82	25.71-16.63	
I–72/58	9	64.06	18.4	2.7	7.0	7.3
P. euramericana	9	62.4	15.0	2.8	10.0	9.8
I–214	9	63.3	17.6	2.9	7.9	8.3
I–69/55	9	63.7	17.5	3.6	8.2	8.0
P. Canadaensis Moench. Cv	9	61.7	16.5	3.0	10.9	7.9
P. canadaensis	9	58.9	13.0	3.3	16.2	6.0
P. alba×P. bero linensis	15	53.96	22.02	3.34	15.67	5.02
P. schneideri var. *tibetica*	9	55.47	11.12	4.58	28.84	

Biomass and forest density

The biomass of tree is affected by forest density. The average biomass of single tree decreases with increasing density. For example, the biomass of single tree of *P. canadaensis* Moench. *Cv* was 357.9 kg, at forest density of 285 individuals·hm^{-2} and 207.7kg at density of 630 individuals·hm^{-2}. Stand biomass also increases by increasing density. For the same species above, the biomass of stand was 102×10^{3} kg·hm^{-2} at density of 285 individuals·hm^{-2} and 130.851×10^{3} kg·hm^{-2} at density of 630 individuals·hm^{-2} (Shandong Provincial Academy of Forestry Science 1990). Xu (1990) conducted the test of biomass of the I-72 poplar species in Yinan, Shandong Province, and the result also obeys this rule.

Puri *et al*. (1995) studied the biomass and distribution of roots of 9-year-old poplar stand with different plant and row spacing (2 m × 2 m, 4 m × 4 m, 6 m× 6 m). Result showed that the biomass of coarse root decreased with increase of plant and row spacing. It was 29.8×10^{3} kg·hm^{-2} in the stand with spacing of 2 m × 2 m and 5.6×10^{3} kg·hm^{-2} in the stand with spacing of 6 m × 6 m. In contrast, the biomass of fine root increased significantly with increase of spacing, from 13.8×10^{3} kg·hm^{-2} in the stand with spacing of 2 m × 2 m to 23.0×10^{3} kg·hm^{-2} in stand with spacing of 6 m × 6 m.

Lodhiyal *et al*. (1994) studied the biomass and nutrient cycling of poplar clone D121 (*Populus deltoids* Marsh). The total net primary productivity of the high-density plantation (4 years old, with 666 trees·hm^{-2}) was conspicuously higher (32.4×10^{3} kg·hm^{-2}·a^{-1}) than that (20.0×10^{3} kg·hm^{-2}·a^{-1}) of low-density plantation (5 years old, with 400 trees·hm^{-2}).

Carbon storage of poplar

Little research was conducted on carbon storage of poplar in China. Ma *et al.* (2002) measured the tissues' carbon content rates of 8 tree species and 10 shrub species in North China. The mean tissues' carbon content rates of these species were 0.4750, 0.5125, 0.4880, 0.4764, 0.5105, 0.5010, 0.5158 0.5118, and 0.4897 respectively for *Querus liaotungensis*, *Betula platyphylla Populus davidiana*, *Tilia tuan*, *Pinus tabulace formis*, *Platycladus orientalis*, *Larch Larix principis –ruppechtii, Picea koraiensis,* and ten shrub species. Tang (2004) analyzed the dynamic carbon storage of 10-year-old I-69 poplar plantation in Lixiahe region of Jiangsu Province. Results showed that the total carbon storage of the plantation was approximately 136.2×10^{3} kg·hm^{-2}, the carbon storage of all trees was 74.1×10^{3} kg·hm^{-2}, and the net production of carbon of trees was 11.1×10^{3} kg·hm^{-2}·a^{-1}. His study suggested that the I-69 plantation has high production and carbon storage and development of fast-growing and high-yielding poplar plantation can play a great role in carbon cycle in atmosphere.

Fang (1996) evaluated the forest productivity of China and established a model for estimating biomass of poplar by forest volume: B=0.4754V+30.6034. This model provides us a basis for further estimating the carbon storage of poplars in China.

Vegetation productivity can be expressed as its dry weight or carbon storage. Forest biomass can be turned to carbon storage by converting coefficient. The common used converting coefficient is 0.5 (0.5g C per gram dry mass) for evaluating carbon storage (Cao *et al*. 2002). Some researches indicated that in middle latitude areas carbon content of wooden plants accounted for 50% of dry biomass in weight, and that of grass or crop about 45%. According to this theory, Zhang (2003) determined the converting relationship between dry weight and carbon storage of different vegetation types in Changbai Mountain of Northeast China. Wang (1999) also used this coefficient to study carbon storage spatial distribution of terrestrial natural vegetation in China.

Problems and suggestion

Although poplar distributes widely in China, the study on biomass of poplars started late in China and the distribution of study location is not harmonious in region. Many distributing areas of poplar are still lack of data. As a result, it is very difficult to estimate poplar biomass exactly in a large scale. Most of the studied poplar forests are artificial forests and one-story forests. So far little research has been carried on natural forests and multi-story forest of poplars. Furthermore the biomass data of sub-tree and herb are lack in some studies even. The present studies on poplar biomass mostly focused on young stands, about 10 years old, even some of them are one year old. In north China, the rotation of most poplar plantations is about 20 years. Data of old age plantation are less for estimating the biomass of mature stands. As for root biomass of poplars, most of reports concentrated on young and middle age stands. It is valuable for us to study the root horizon and upright distribution.

Except the basic forest management measures, such as fertilization and watering, planting some vegetables in forest can also improve soil condition and increase biomass (Xu and Chen 1987; Xing 1991). Generally, poplar is planted as high yield species with big plant and row spacing. Some economic vegetables, such as short bean and other farm vegetable (Xu and Chen 1987; Sun 1995), can be cultured before the stand close up to raise economic benefit and improve soil quality

Poplar is fast-growing and high yielding species which has great ability to product and immobilizing carbon. We should carry out the research and evaluate the immobilizing ability of carbon, so as to provide scientific base for carbon trade between China and developed countries. “Three North” (Northeast region, Northwest region and Central north) protective forest, which is mainly composed of poplar, is at the mature stage or over mature stage. Generation must be done shortly. We should seize the chance to strive for forestation and reforestation projects to enhance economic benefit.

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